EM Propagation (METOC Impacts)

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LONG TERM GOALS

Develop electromagnetic propagation models, that perform equally well over land and sea and in the presence of anomalous propagation conditions for both surface and airborne emitters, for use in operational or engineering propagation assessment systems.

OBJECTIVES

Develop an advanced unified hybrid radio propagation model based on parabolic equation and ray-optics methods for both surface-based and airborne applications. This model is named the Advanced Propagation Model (APM) and is the model used in the Advanced Refractive Effects Prediction System (AREPS). Other objectives are to develop a propagation model for earth-satellite geometries suitable for inclusion into the Advanced Propagation Model (APM) or alternately, suitable for transition to the Advanced Refractive Effects Prediction System (AREPS) and the Naval Integrated Tactical Environmental Subsystem (NITES) II. As part of this development effort, an enhanced absorption model will be updated and rain attenuation models will be included within APM and the earth-to-satellite model (ESPM). We will also perform a sensitivity study of the structure parameter using the Rough Evaporation Duct (RED) measurements. As a result of this study we will develop a suitable algorithm within APM accounting for turbulent effects in the marine boundary layer, providing a variance of the predicted instantaneous field strength.

APPROACH

We develop parabolic equation (PE), ray optics, waveguide, and other models as necessary to produce both accurate and efficient models to be used in propagation assessment systems. In many cases we can use variations of existing models to achieve this goal, but sometimes completely new models are necessary. Once developed, these models are compared to other models and to experimentally

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collected propagation data for verification of accuracy. We stay abreast of other researchers' newest models by reading current literature, participating in propagation workshops, and attending conferences as appropriate. We continually examine new modeling techniques that may offer improvements in prediction accuracy or execution time. There is a strong international exchange of ideas and techniques in this area, as some important work is performed outside of the USA. This ongoing project has developed a hybrid ray optics/parabolic equation propagation model for assessing the effects of the atmosphere and the environment in general on electromagnetic emissions in the range of 2 MHz to 57 GHz for both surface based and airborne transmitters.

The vertically varying profile computed from bulk models is considered to represent the refractive mean and is the only atmospheric input normally considered in predicting field strength over water. The result is that the prediction also represents a *mean* instantaneous field strength, and in reality the field will fluctuate about this mean by some variance that may be a function of the turbulent structure parameter. The bulk measurement data set that we will use to obtain vertical refractivity, as well as structure parameter profiles, will be that taken during the Rough Evaporation Duct measurement campaign [1]. We can then apply the structure parameter to perform a sensitivity study using APM to determine the variations in the field strength due to this parameter. The technique used within the APM to do this will be based on a modification to the method developed by Hitney, which considered applying fluctuations in the refractive index due to the turbulent structure parameter to model tropospheric scatter [2].

This project is divided into two tasks: (1) Metoc Impacts and EM Performance Assessment for Earth-Space Geometries, PI Dr. Richard Sprague; and (2) Atmospheric Surface Layer Turbulence Effects on Microwave Signal Level, PI Amalia Barrios.

WORK COMPLETED

METOC IMPACTS AND EM PERFORMANCE ASSESSMENT FOR EARTH-SPACE GEOMETRIES
A ray tracing capability for earth-space geometries was developed for this effort. The new ray-trace assumes a height dependent (range independent), refractivity structure which is supplied by the user, if possible. The user is also required to specify locations (sub-latitude/longitude of terminals, height(s) relative to ground) for the terminals, RF frequency, transmitter power, and antenna gain information at both terminals. We also developed and implemented a ray homing procedure which iterates on ray launch angle to determine that ray which connects transmitter and receiver (satellite). A two-dimensional (range and angle) iteration scheme was developed to determine the earth-reflected ray parameters. We investigated several options for the rain attenuation model and have implemented the International Telecommunication Union (ITU) recommended model. We have also implemented the ITU recommended model for computing losses due to gaseous absorption as this will be a critical component in the resultant field strength typical for SATCOM frequencies and geometries.

ATMOSPHERIC SURFACE LAYER TURBULENCE EFFECTS ON MICROWAVE SIGNAL LEVEL
The frequencies at which radio data were collected during RED were 3 GHz, 9.7 GHz, and 17.7 GHz. The transmitting antennas were located at two heights above the surface – 4.9 m and 12.7 m, with the receiver height at 4.7 m, and the radio propagation data was collected for each combination of 6 transmitter/frequency geometries for a period of 5 minutes each. The signal was sampled at a rate of 256 samples per 5 minute period. The mean of the propagation loss, along with the standard deviation for each 5 minute period was computed. The Naval Postgraduate School (NPS) bulk model [3], which computes the evaporation duct refractivity profile based on bulk measurements of air/sea temperature,

wind speed, and humidity was modified to also compute the height-varying structure parameter, C_n^2. The PE algorithm within APM was modified to incorporate a random realization of the turbulent fluctuation portion of refractive index based on the 1-dimensional Kolmogorov spectrum, which is a function of the outer scale length, L_o, and C_n^2. The APM was then run 256 times (i.e., 256 random realizations) for each 5 minute period to simulate the data collection procedure. The outer scale length in this implementation is still an unknown and was varied for each set of runs to determine the best possible value and if a relationship can be obtained between L_o and the evaporation duct height or Monin-Obukhov length. The mean and standard deviation of the predicted loss values were then computed and analyzed against observations to determine the validity of the current implementation to model turbulent effects.

RESULTS

METOC IMPACTS AND EM PERFORMANCE ASSESSMENT FOR EARTH-SPACE GEOMETRIES

Although APM contains a ray-trace capability, it employs small angle approximations which make it suitable only for terrestrial paths. For earth-satellite (ES) geometries, large ray angles (relative to the horizontal) are the rule and so a more general ray-tracing capability had to be developed. However, while large ray angles are the rule, the most critical scenario for the use of this assessment tool is envisioned to be communication to satellites low on the transmitter's horizon, i.e., at small angles. This is especially true in extreme ducting conditions when ray trapping may exclude any communication between the satellite and a ground station. Under these conditions the signal loss can also become very large, making communication impossible even if a signal path can be established.

Some examples of the ray trace results were shown at the program review earlier this year. For this discussion, we include an example below.
Figure 1 shows the rays connecting a transmitter at 1 km height to a satellite at 1000 km height for 9 and 30 degree angular offsets. Generally, the reflection point is less than 50 km from the transmitter site for all realistic scenarios. Given the latitude/longitude of the reflection point the electrical parameters (conductivity and dielectric constant) can be determined from world maps of these parameters. Given the electrical parameters and the ray angle at the earth, the complex reflection coefficient can be evaluated. The reflected ray angle at the earth also allows the amplitude divergence factor of the reflected ray to be evaluated. These factors are used, together with the spreading loss ('free-space' loss) and other loss mechanisms, to determine the signal strength at the satellite.

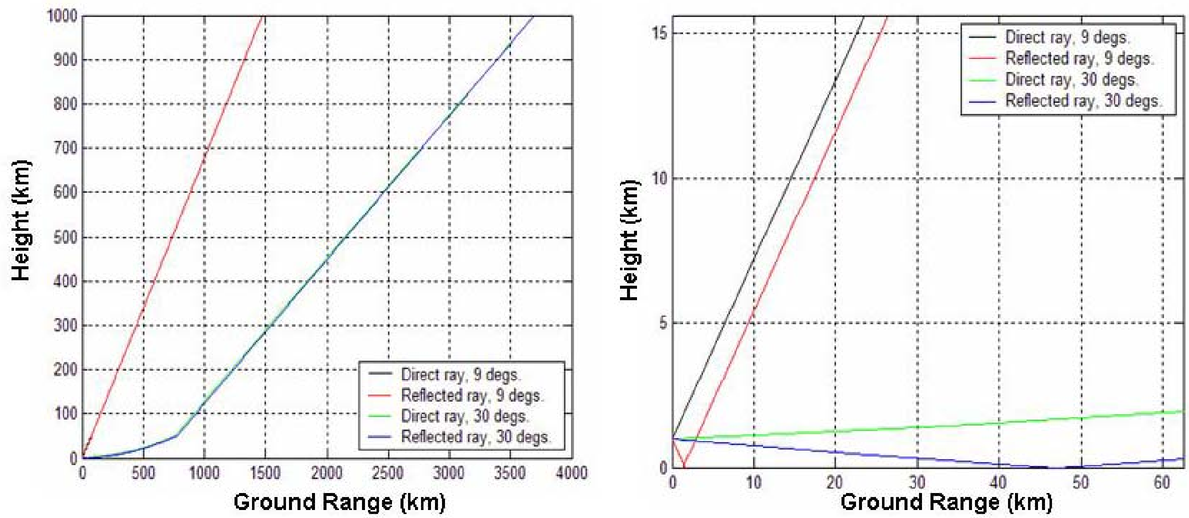

Figure 1. Examples of direct and reflected rays joining a transmitter to a satellite at a height of 1000 km. Right image shows detail at earth reflection point.

Figure 2 shows the trapping effect of a large height gradient of refractivity. We note the extreme sensitivity to ray launch angle for these low angle rays. Analysis of these scenarios are critical for optimization of system performance, both for orbiting satellites at heights of 1000 km and up and for geo-stationary satellites when the transmitter site is located at high latitudes, i.e., submarines operating in polar regions.

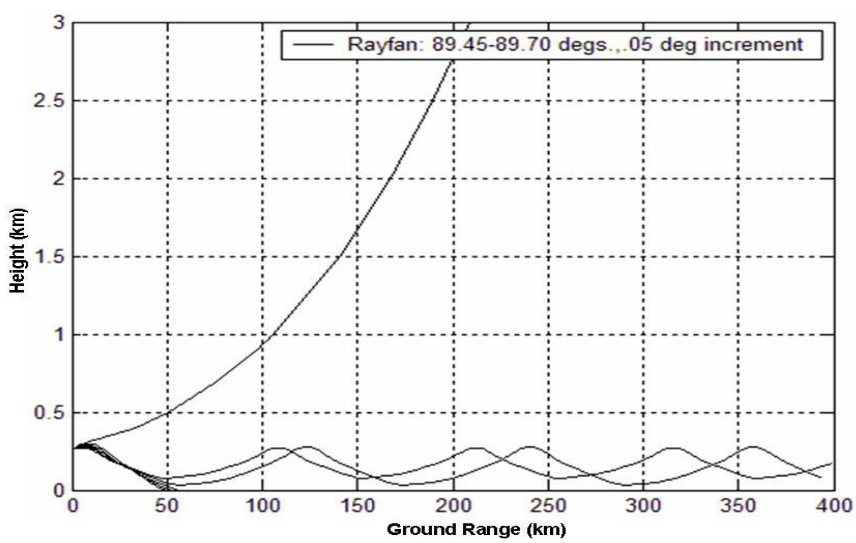

Figure 2. Examples of possible rays in a large refractivity gradient scenario. In scenarios ray launch angle is critical to successful communications.

Finding the rays which connect transmitter to satellite in these extreme refracting scenarios can be time consuming, given the obvious sensitivity to initial launch angle. Improving performance of the homing procedure under these conditions is a focus of future work.

In addition to the 'free-space' loss suffered by the signal on its path to the satellite, another important loss mechanism is attenuation due to rain. This loss is frequency and rain intensity dependent. It has been the subject of quite a bit of research over the last 30 years or so and many predictive models have been developed [4]. Several of these models take the mathematical form $A=PR^{m}$, where A is the attenuation rate , P and R depend on frequency and location and R is the rain rate, which is also a function of location.

The International Telecommunication Union (ITU) recommends a model, the 'DAH' model, developed by Dissanayake, et al.[5]. It has been shown that this model consistently provides the most accurate long-term predictions at Ka band [6]. The derivative model recommended by ITU is extended to cover the entire relevant frequency band (1 GHz ~ 400 GHz) and we have chosen this model for use here. Global rain rate probability data and other parameters necessary for implementation were obtained from ITU.

Given the ray parameters (launch angles and reception angles, ray path lengths, phase path lengths, earth reflection angles) , antenna gain values, attenuation due to gaseous absorption, and rain attenuation for both direct and reflected rays, received power at the satellite can be estimated.

ATMOSPHERIC SURFACE LAYER TURBULENCE EFFECTS ON MICROWAVE SIGNAL LEVEL
Over each 5 minute sampling period, the radio propagation data varied from its average by a standard deviation value determined from the 256 samples during this period. This variation is attributable to turbulence and not noise due to the fact that the signal variance was not consistent across the three frequency bands used in the RED experiment. This is shown in Fig. 3 as the standard deviation for much of the X-Band data and roughly all the S-Band data is 1 dB. The standard deviation for the Ku-Band propagation data, however, is distributed fairly evenly from 1 to 6 dB for the entire two-week IOP. Therefore, only the Ku-Band radio data was used in the analysis.

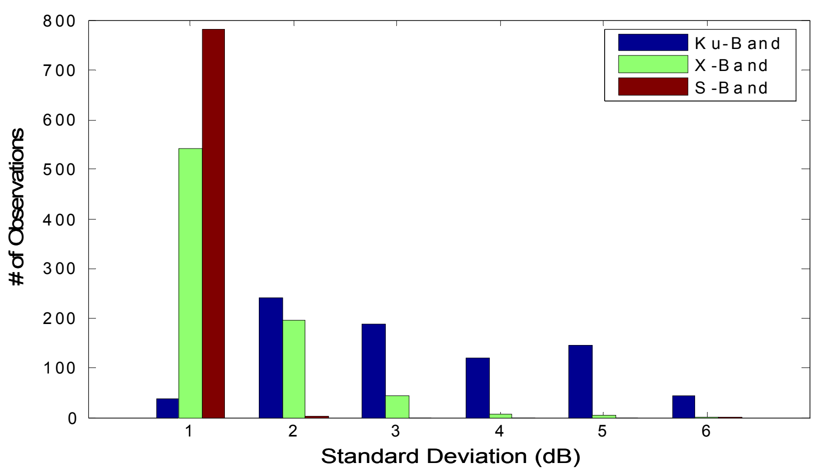

Figure 3. Standard deviation of radio data collected during RED for all 3 frequency bands .

Based on Ishimaru [7], the relationship between the particular wavelength of consideration and the propagation path length used in this experiment suggests that the optimum value for L_o is 10 m. However, this value did not produce the lowest RMS error of standard deviation when compared with observations. According to Tatarskii [8], there is a relationship between L_o and the sensor (i.e., antenna) height, which is assumed to be 0.4 times the antenna height. While the receiver and lower transmitting antenna heights were roughly equal (4.7 m and 4.9 m, respectively), the higher transmitting antenna height was at 12.7 m. According to [8], this would suggest the optimum value for L_o is roughly 2 m for the low antenna and 7 m for the high antenna. A value of 2 m gave extremely poor results when compared with observations. In order to establish a possible relationship between L_o and the particular geometries used for the experiment, APM was run with varying L_o values of 4, 6, 8, and 10 m. Figure 4 below shows the APM-predicted values of standard deviation for L_o=8 m, which is also fairly representative of the qualitative comparison for L_o=6 m.

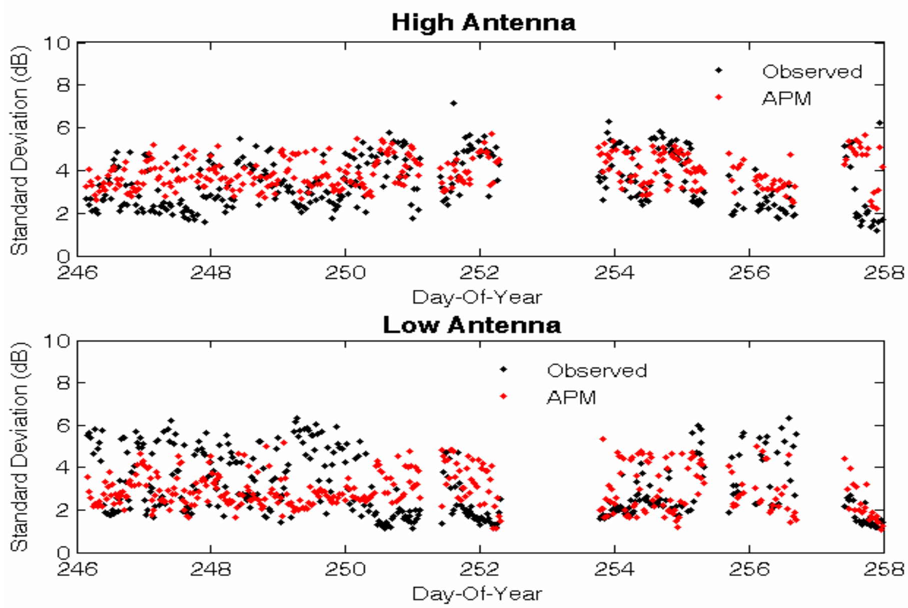

Figure 4. Observed and APM-predicted standard deviation for L_o=8 m.

The two L_o values of 6 and 8 m provided the lowest RMS error between the computed and observed standard deviation. Table 1 shows the overall results for all L_o values used in the simulations. For all values of L_o the RMS error was consistently lower for the high antenna observations than for the low antenna. However, at the lowest RMS error of 1.27 dB, this still provides a 21% error when considering the dynamic range of 1 to 6 dB in the observed standard deviation.

Table 1. RMS Error of APM predicted and observed standard deviation (dB).

L_o (m)	High Ant.	Low Ant.
4	1.60	2.17
6	1.27	1.88
8	1.29	1.74
10	1.53	1.79

From initial results for the high antenna, the current implementation of the Kolmogorov spectrum produces reasonable values simulating turbulent effects. However, this is not the case for the low antenna as there is consistently poorer agreement with observations. It is widely accepted [7] that the outer scale length L_o is a parameter that is variable in height and should not be treated as a constant as was done here. Therefore, as part of the second-year effort for this task, a similar analysis will be performed with a height-varying L_o.

IMPACT/APPLICATIONS

The goal of this work is to produce operational radio propagation models for incorporation into U.S. Navy assessment systems. Current plans call for the APM to be the single model for all tropospheric radio propagation applications. As APM is developed it will be properly documented for delivery to OAML, from which it will be available for incorporation into Navy assessment systems. Recent optimizations and enhancements of APM not only benefits the U.S. Navy but also **unifies** the overall military EM performance assessment capability by having a single high-fidelity propagation model that performs equally well over land and sea and in the presence of anomalous propagation conditions.

With the development of the ESPM, the Navy and Marine Corps, as well as Army communicators, will also have a propagation model for SATCOM performance assessment to allow optimization of communications.

TRANSITIONS

All APM modifications and added capabilities transition into the Tactical EM/EO Propagation Models Project (PE 0603207N) under PMW 180 which has produced the Advanced Refractive Effects Prediction System (AREPS). Academia and other U.S. government are also utilizing APM/AREPS. APM is currently being used by foreign agencies as the underlying propagation model within their own assessment software packages. APM has also been adopted as the preferred propagation model in the Evolved Sea Sparrow Missile (ESSM) International Simulation (IntSim) program created by NAWC-WD. IntSim is a NATO program with the following participating countries: Australia, Belgium, Denmark, Germany, Netherlands, and Norway. APM involvement within IntSim is via the Ship Air Defense Model (SADM), which is the RF propagation assessment module within IntSim and was developed by BAE Systems, Australia.

RELATED PROJECTS

This project is closely related to the synoptic and mesoscale numerical analysis and prediction projects pursued by NRL Monterey.

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PUBLICATIONS

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